Do You Read Me? On the Limits of Manufacturing Part Numbers for Communicating Product Variety

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Abstract. Manufacturing part numbers (MPNs) are used to communicate product variety both for internal purposes and for external representation to customers. To simplify this communication, MPNs have been originally developed as human-readable abbreviations of those characteristics that uniquely identify a product variant out of a modular system, thus acting both as an identifier and a description. However, the increasing complexity of customer requests forces component manufacturers to expand their product portfolios, thus pushing the descriptive character of a classic MPN to its limits. Ongoing digitalization drives product identification towards fully-digital possibilities. Nevertheless, in reality component manufacturers still rely on MPNs. Against this background, the purpose of this paper is to analyze the cognitive and systemic characteristics of the MPN with regard to the underlying product structure (PS). As a result, we derive evaluation criteria for the quality of mappings from PS to MPN and apply them to typical business use cases. In doing so, we provide the first systematic overview and discussion of factors that determine MPN's utility and usability as well as give practical guidelines for component manufacturers regarding the selection of appropriate MPN types.

1 INTRODUCTION

With the growing trend of customization and the overall direction towards a lot size of one, manufacturers are facing new requirements of representing their product portfolio in a clear and structured way, as well as understanding their customers' demands. This is a concern particularly in the business-to-business (B2B) markets, where complex machines (and even machine parts) consist of numerous modular elements, thus offering almost unlimited configuration possibilities to the customers. For example, compared to a BMW series 7 who offer as many as 10^{17} possible variants [1], Lenze AG claims to have up to 10^{30} configuration possibilities just for their gear motor, each of which resulting into a separate identifier. However, if not structured properly, an unnecessarily high product variety can become counter-productive, since customers can get confused about the differentiation among product variants [2]. In this way, while a modular product structure promises a compromise between customer-driven customization and manufacturer-motivated standardization [3], the structuring and the communication of "what's possible and at what price" is a very important, but also a challenging task.

In this context, alphanumeric strings have been used to communicate product variety both for internal purposes and for external representation to customers [4]. For referring to these strings various denominators are common practice, e.g., type code, order code or ID, part ID or number. For reasons of simplicity, we will use the term *manufacturing part number* (MPN, see Section 2.3) throughout this paper. MPNs are codifications of product

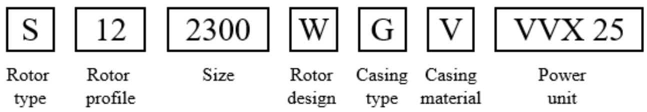

Figure 1. Exemplary MPN structure for a rotor system (Lautner GmbH)

characteristics or functions (e.g., information on its structure, material composition, production process) and act as a distinct identifier of a certain product combination (Figure 1). Typical use cases for MPNs range from initial product search to reordering or maintenance of a particular machine. Within this paper, we focus on the appropriateness of such numbers for the purpose of communicating product variety, i.e., visible features. In practice, oftentimes the corresponding stakeholder is provided with relevant supplementary documents that explain the structure and the logic of the MPN and accelerate the process of "deciphering" its information (e.g., tables, graphs, dictionaries). However, although originally developed to be human-readable in order to simplify the customer-supplier communication, we ask the following questions, since many things have changed:

- *Is it still necessary and monetarily reasonable to use MPNs that are human-readable[4]?*
- *Where are the limits of different MPN types and what should the selection of the appropriate MPN depend on?*

In particular, there exist various reasons to switch to a completely digital MPN. First, the descriptive character within any human interaction works only as long as a certain length and complexity of the MPN is not exceeded [5]. For products with a rich variety the number of product characteristics and, consequently, configuration possibilities, is very high. In this way, at some point, the MPN may become too complex and confusing for involved stakeholders. In case a customer is not able to fully understand how a specific MPN relates to the corresponding product may result in delays or incorrect orders, potentially damaging the customer-supplier relationship.

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[4] In this publication we define "human-readable" as the code feature to be read *and* comprehended by the human, while "machine-readable" or "digital" can be processed *solely* by a digital medium

Second, since B2B customers have to deal with dozens of such structures a day from different suppliers, they are no longer willing to invest their time in understanding the internal product structure of each of their partners [6]. This leads to the overall decline of the technical know-how in the market, thus making human-readable MPNs containing these technical details rather obsolete. Third, company mergers and acquisitions may result in inconsistencies and redundancies in the data management[5] [7]. On the one hand, both companies could have similar nomenclatures (or even same serial numbers for different products), thus causing confusion for the future product handling. On the other hand, the customers of the company would get an additional structure to deal with, thus increasing the complexity of variant management and communication.

Nevertheless, despite all advantages mentioned above, it would be narrow-minded to claim that a digital (i.e., only machine-readable) MPN is a universal solution for the efficient communication of the product variety for every manufacturer. The most obvious argument against the abolishment of human-readable MPNs is the complete dependency on a digital device (e.g., QR code reader, barcode scanner) to read and understand the MPN. Examples of situations when this could be problematic include product manufacturing, where a person using an MPN as a guideline for assembly would have to interrupt the production process, or general network coverage problems leading to the inability to use a central referral database. As for other non-functional requirements, the transition to the digital MPN would result in additional hardware-related costs as well as general efforts for restructuring. Moreover, such an initiative could also meet the opposition of the users themselves, who are generally reluctant to any structural changes, since they are used to the way the things are currently handled [8]. Finally, since a digital MPN has all the freedom regarding how much information it can hold and thus communicate, product manufacturers might get tempted to put too much information (if not all of it) in one single digital ID, e.g., a QR-code, thus overwhelming their customers, who would spend additional time for finding the relevant information [9].

Overall, while digital identifiers such as RFID integrated into ERP systems have been proposed more than a decade ago, the reality shows that product and part manufacturers are still far away from the best practice, which calls to find out why. Motivated by the heterogeneity of the involved stakeholders and an overall specificity of product configuration in the B2B markets, we believe that different MPN structures are needed depending on respective application scenarios. Therefore, by applying methods from information theory and insights from cognitive science we analyze relevant characteristics of MPN as well as define evaluation criteria for how well the MPN can map the underlying product structure (PS). By showing that there exist five typical business use cases and thus no universal MPN we contribute to the theoretical discussion on knowledge representation and pave the ground for further research. In addition, as current pragmatic solutions of the practitioners are rather narrow-minded without considering their efficiency, we give practical guidelines for the selection of an appropriate MPN.

The remainder of this paper is organized as follows. After giving a short overview of the theoretical background in Section 2, the aspects of MPN and PS, as well as evaluation criteria of the MPN-PS mapping are explained in Section 3. The evaluation criteria are then applied to the typical business use cases in Section 4. The paper concludes with a summary of the results, possible limitations as well as future research opportunities.

2 THEORETICAL BACKGROUND

2.1 Code Function and Code Word

In general, a code is an agreement on sets of meaningful symbols for the purpose of information exchange between a sender and single or multiple recipients (e.g., [10], [11]). For this purpose, the sender encodes the information, which needs to be decoded by the recipient with the same coding schema. From a mathematical perspective, a code is an injective mapping from a domain element ($x \in D$) to an element of an image set ($y \in I$). Furthermore, the resulting image must not be empty:

$$f: D \to I^+$$

In the context of codes D and I are considered finite alphabets, i.e. arbitrary sets of symbols with a limited number of elements. In general, codes can be applied for abstracting or abbreviating information and its dependencies. In that sense, not only the Morse code or the internet acronym LOL ("laughing out loud") is a code, but also traffic lights.

From a communication perspective, a code is a translation from the sender's original information or message to some communication means (encoding or encryption), e.g., digital impulses, sound or flags. If the code function is known to the recipient, the original information becomes easily decodable (decoding). Otherwise, the recipient is not able to restore the information at all (no decryption possible). Each code word (a sequence of symbols), which is derivable by the code function, is called a valid code word. Following these definitions, the transfer from a product structure (PS), i.e., simplified a set of product characteristics with certain values, to some part number, e.g. an MPN. The code function is the schema which characteristics are considered and how the corresponding values are represented in the resulting code word, i.e., a product-specific MPN. In the remainder of the paper, in general, we will not distinguish between the code function and the resulting code word and use the term 'code' synonymously.

The application of codes is closely related to *efficiency*, which is achieved by reducing complexity regarding the original information, i.e. by abstraction, abbreviation, or compression. As it takes the effort to design a code, a code gets more efficient the more often it is used. Additionally, some codes use a modular architecture (i.e. decomposition of a complex system in separate functional units) for reasons of efficiency.

With this theoretical background in mind, we consider the relation between code functions and MPN generation from a psychological perspective in more detail in Section 3.

2.2 Variant Management

Due to a high level of heterogeneity and a tight customer involvement both in the product design and manufacturing [12],

[5] Project experience of the authors shows that these kinds of problems may arise even between units of the same company.

B2B manufacturers are constantly searching for new ways of standardization without diminishing their ability to go the last mile for their customers [13]. In this context, the introduction of the modular product design (i.e. building a complex system out of exchangeable modules with a clear function and defined connectivity interfaces) has led to a series of organization and production changes, thus expanding configuration possibilities almost exponentially [14]. This resulted in the introduction of such manufacturing concepts as Mass Customization [15] and an overall higher interdependence of the supply chain partners.

However, while a modular product structure promises a compromise between customer-driven customization and manufacturer-motivated standardization [16], the variant management throughout the whole product lifecycle becomes increasingly challenging. A good overview of the sources of complexity in engineering design and manufacturing is given in [5], where complexity is considered as a multi-faceted measurement that is influenced both by endogenous and exogenous drivers.

ElMaraghy et al. [17] define variety as "a number or collection of different things of a particular class of the same general kind", with a variant being an instance of a class that exhibits (slight) differences from the common type. The overall goal of modular product structures is the minimization of *inner variety* while maximizing *outer variety*. In other words – to offer customers as many individualized products as possible with as few parts in production as possible [16]. Additionally, when talking about variant management it is reasonable to differentiate between its two levels – strategic and operative. While the *strategic level* concentrates on "determining and mastering the variety of the product portfolio in such a way that it is aligned with the competitive and the product strategy", the *operative level* implements and secures the overall variant strategy [18]. This publication focuses on the operative level since MPNs are used for the identification and representation of a certain product instance or a category of product combinations, thus supporting the actual implementation of variant management. At this point, we assume that a modularization process has already been conducted and a modular product structure is already given as an input. More information on these steps can be found in [16].

The challenge of operative variant management resulted in the emergence of a specific market for so-called CPQ-systems [19], which can be integrated into existing enterprise software. CPQ software enables product configuration (C), its respective pricing (P) and creation of a unified quote containing all necessary information of the offer (Q). While these quotation documents contain all the details about the desired machine or its component, MPNs are a more compact information representation used for internal and external communication of the product variants and variant identification. As of today, both the topics of CPQ-systems and MPNs have not been devoted enough academic attention, even though they are used in practice on an everyday basis.

2.3 Product Identifiers

Since the topic of variant management and product identification involves different research disciplines such as engineering, marketing, information systems or even psychology, there exist no universal definitions or terminology. The challenge lies in the applied nature of the topic and its historical development – not only do the terms and labels differ between companies (especially across different domains and fields of operation), but sometimes even within the same company, depending on the department and the use case. For example, the term "type code" is often used for the description of product groups, even though this term has already established itself in the context of digital storage media, e.g., DVD and Blue-ray [20]. Other misleading terms for the same purpose include "Product Key" or "Type Designation Key", which are used either when installing software programs or when describing specifications and configurations of computer drives [21]. The fact that there exists no standard (international) specification or central point of reference makes it even more confusing for the communication with partners and customers.

Irrespective of the use case, each product or service needs a certain description for the purpose of identification and explanation, containing compressed information in the form of characteristics. Oxford Dictionary defines *Identifier* (ID) as a sequence of characters used to identify or refer to an element, such as a variable set of data. Such an ID can refer either to a unique class of objects with a certain level of abstraction (i.e. products that are grouped based on a certain set of characteristics while, possibly, ignoring further details), or be used for an identification of a specific physical object. A typical example of the object identification is a serial code or *Serial Number* (SN), which is usually comprised of numerals even though other typographical symbols are also possible. In most cases, the SN is built with no particular logic or predefined structure, as it is assigned incrementally or sequentially to an item in the production [22] and thus cannot be read or interpreted by any of the stakeholders. On the contrary, *Manufacturer's Model Number* (MMN) is a solely marketing-driven succinct and catchy description with the purpose of evoking certain associations and interpretations when being communicated to the customers. However, the inevitable problem with the MMN is its necessary level of abstraction – driven by either customer's cognitive capacity (e.g., the ability to remember a certain string) or system limitations (e.g., input fields of ERP systems are often limited in length), the MMN has to concentrate only on the most important product characteristics (e.g., iPhone SE 64 GB black) thus neglecting other valuable product information [4].

Against this background, a compromise between production-driven machine readability and marketing-driven human-readability can be reached by using the term *Manufacturer's Part Number* (MPN) [23], which is the focus of our publication (Figure 2). While also being an identifier for a unique class of objects just like MMN, the MPN contains much more information and is historically built upon a certain predefined structure, which is often sent directly to the customer.[6] Here, an SN is a particular instantiation of an MPN acting as an identifier within a certain context. Therefore, an SN alone cannot be used as a unique identifier (UID), i.e., guaranteed to be unique among all identifiers used for those objects and for a specific purpose, as companies may have identical serial number systems for different products within their product portfolio. Instead, a UID can be created by combining both the MPN and its particular instantiation SN, e.g., "Model X" and "Serial Number 238912". From a mathematical point of view, an MPN is a code word, which

[6] For example, the manufacturing company SEW has a 15-page document showing the structure of their MPN.

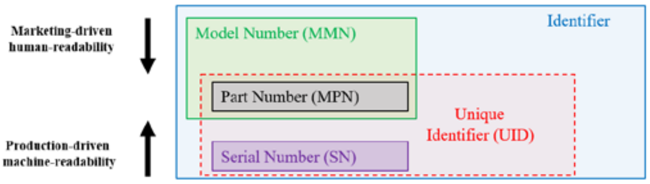

Figure 2. Different identifiers and their interrelationship

is derived by a code function from the product structure taking a subset of characteristics into account (cf. Section 2.1).

3 MPN-PS MAPPING EVALUATION

3.1 Methodology

For the purpose or transparency and traceability of our results, we first give an overview of the methodology used in this paper (Figure 3). It consists of the metaphases *Orientation* and *Application of the MPN*, each containing two consecutive steps along with the applied technique (textual description) and preliminary results (rectangles).

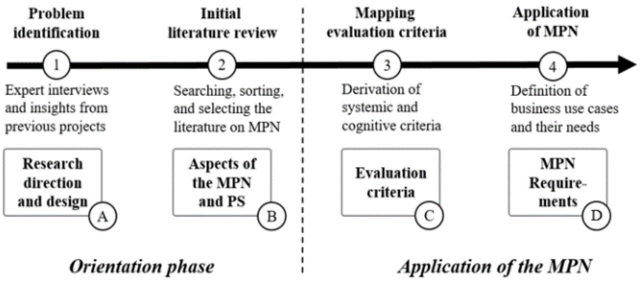

Figure 3. Overall paper methodology

Due to the applied nature of our research, first, we contacted the practitioners in order to identify current problems in variant management and product configuration (Step 1). For this, we cooperated with one German consulting company, which specializes in CPQ-Software for complexity reduction and simplification of the quotation process. By conducting semi-structured expert interviews [24] with eight of its previous customers, we were able to gather first insights on the challenges concerning MPN and confirm that different use cases require different types of MPN (Result A).

As a second part of the orientation phase, we then conducted a systematic literature review (Step 2). Sadly, despite its practical importance, the topic of MPN structure and its deployment has not received enough academic attention yet. Therefore, in order to place our research within an ongoing theoretical discussion, we also looked at the adjacent topics of variant management, complexity in manufacturing, and production identifiers. In this way, we were able to identify various MPN aspects, which are relevant for the communication of the product variants (Result B).

The second phase dealt with the application of the MPN in the real-life context. For instance, based on the results from the orientation phase we were able to derive systemic and cognitive evaluation criteria for the MPN-PS mapping in Step 3 (Result C). Since this publication is meant to open a discussion on the topic, we did not provide any specific metrics but remained merely on a conceptual level. Finally, with the help of the conducted expert interviews and based on our own experience from previous projects in Step 4 we defined five business use cases for the MPN deployment, including stakeholder description and requirements for the MPN. In this way, it was possible to show that there exists no universal MPN, but rather that its selection depends on certain industrial, company, and customer characteristics (Result D).

3.2 Formal definition

While it may seem that an MPN is just a string of characters, it has numerous systemic and cognitive aspects, which influence its communication and variant management in general. In this context, MPN generation can be seen as a specific mapping $\mathcal{M}$ that is used to represent a given (fixed) product structure in an understandable way (cf. Section 2.1), aiming to be both complete and easy to use (Figure 4). With different product structures and company's specificities, there are many ways to approach such a mapping, ranging from a mere enumeration of all possibilities up to the complex nested configurable structure, meaning that the quality of the mapping can be evaluated for a specific context. We define such an evaluation function $\mathcal{E}$ of mapping $\mathcal{M}$ with respect to a specific need or application of the generated MPN, defined by a set of evaluation criteria $\boldsymbol{c} = [c_1, \dots, c_m]$ and corresponding outcomes $\boldsymbol{x} = [x_1, \dots, x_m]$:

$$\mathcal{E}(\mathcal{M}, \boldsymbol{c}) = \boldsymbol{x} \; with \; x_i \in [0..1]$$

Based on the insights from the expert interviews (Figure 3, Step 1) and literature review (Figure 3, Step 2), in this publication, we concentrate on the general mapping $\mathcal{M}$ and the definition of the corresponding evaluation criteria as well as their testing for different use cases. The subsequent optimization problem, i.e. finding an optimal MPN with respect to a given set of criteria, is beyond the scope of the publication and is left for the future research.

3.3 Product and MPN structure

When talking about the evaluation of the MPN it is important to differentiate between two different types of structure (Figure 4).

The *Product Structure* is a rigid arrangement of elements that is used to depict product compositions and configuration possibilities. Unlike the MPN structure, the actual product structure (i.e. what elements a complex machine consists of, what possible combinations are there, etc.) states the core of the value proposition and thus cannot be changed. In this regard, the *Number of Product Characteristics* shows which parts of a complex product can be substituted or exchanged if desired. Similarly, such a modular product composition and interface specifications determine the *Configurable Variety*, thus enabling satisfaction of customer heterogeneous requirements. However, as mentioned earlier, a

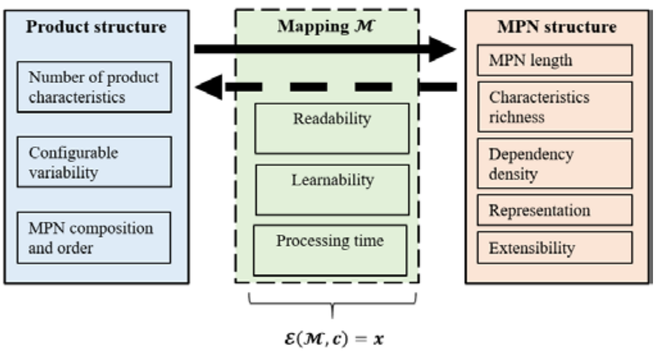

Figure 4. Depiction of the product structure with the use of MPN

higher configurable variety does not necessarily mean a better portfolio, since an excessively high variety can even be counter-productive, as customers can get confused about the differentiation among product variants. Finally, the actual *Composition of the MPN* along with the sequential arrangement of the characteristics within is influenced by the product structure. In other words, the stakeholder is able to read and understand the information encoded in the MPN only as long as he/she knows what symbol is responsible for what characteristics.

The *MPN structure*, on the other hand, is flexible and can be adjusted according to the company's preferences. A cleverly picked MPN can enhance human understanding and thus its overall manageability and understandability, whereas a bad MPN may confuse both the company employees as well as their customers. This includes the *Length of the MPN*, which may sometimes be challenging, since many ERP systems (e.g., SAP) have an integrated limit on the string length, thus indirectly forcing product manufacturers to use shorter codes [4]. Another important MPN characteristic is an average *Characteristics Richness* showing how many variants are encoded inside single characteristics. This aspect is especially important if the MPN is human-readable and a person operating it has to remember all the variants of every characteristic by heart. Finally, the amount of configurable feasible solutions is limited by the applicable logical rules (e.g., IF, XOR, AND), which can be summarized by the aspect *Dependency Density*. Although acting as a limitation to the possible solution space, dependency density increases the complexity of the MPN and thus its applicability by a human stakeholder. Looking at the long-term life-cycle of products, another central aspect is the *Extensibility* of the MPN. This is particularly important for products, which are still in the development and it is foreseeable that new characteristics may be added according to customer's preferences or market's development, e.g., by adding functionality by software updates. The level of extensibility can hereby range from practically impossible (e.g., rules defining the MPN structure prohibit any further extension) or cost-inefficient (e.g., requiring database connectivity) to complete freedom (e.g., no limitations within a digital MPN). Finally, the choice of MPN *Representation* type predefines how it will be used between the involved actors. Three possible types of MPN representation can be differentiated, each with its advantage and limitation: (i) human understandable MPN that can be read and assessed without any additional help, meaning that human operator needs to know the MPN structure and characteristic meaning by heart; (ii) human readable MPN that can be read and assessed using a certain (analog or digital) code translator or additive requiring a certain level of know-how of the user; (iii) machine-readable MPN that can contain almost unlimited amount of coded information within product characteristics, without any know-how requirements for the user, but with a high dependency on a digital scanner.

3.4 Mapping evaluation criteria

Once an appropriate MPN and a clear mapping of the product structure to the MPN is created, the question arises how well a human can employ it, with or without any auxiliary means, i.e. how complex the code function is w.r.t. human processing (cf. Section 2.1). If we abstract from specific company restrictions or personal preferences, the human user should be able to map the MPN to a corresponding product 1) quickly, 2) with acceptable accuracy, and 3) without extensive learning. A prerequisite for achieving this is that the MPN and the mapping realized by it are conducive to the way in which humans process information. For example, consider the acronym "TDI" to characterize a property of car motors. If confronted with this acronym in the context of cars, people may already "know" that the car being under consideration has a diesel motor with "Turbocharged Direct Injection".[7] At this point, the question arises: how or why do people know this? If observed separately, these three letters "TDI" could also stand for something else, e.g., "Total Dream Interior", thus describing some arbitrary aspect of the car. The only source for this knowledge is the memory of the person having to deal with the acronym. In other words – the working and usability of MPNs for human users relies critically on the memory capacity of the human user.

The human cognitive system is commonly conceived as consisting of several different types of memory stores [25]. For reasons explained in the following, the two types of stores most relevant for our considerations with regard to MPNs are *working memory* (WM) and *long-term memory* (LTM). Information recently having or currently being processed resides in WM. As such, WM is assumed to be limited in capacity as well as in the duration that content will remain accessible. Although exact estimations vary it seems clear that no more than 10 items of information can be maintained simultaneously [26, 27]. If the information in WM is not used, it will be lost within a few seconds [28]. Human LTM, on the other hand, can store vast amounts of information (see [29] for estimates) over very long time spans (just think of old people telling stories from their childhood). In fact, depending on the usage frequency, information from LTM can be retrieved into WM and information residing in WM may be transferred to LTM for more permanent storage. Going back to the "TDI" example, it seems most likely that knowing that "TDI" signifies "Turbocharged Direct Injection" is retrieved from LTM. If it was not the case, it would have had to be maintained in WM since first learning what "TDI" means. This may be the case when someone first tells you what "TDI" means in the domain of car motors, but on later encounters, it seems unlikely that the meaning of the acronym has been constantly maintained in working memory for the whole time. Given that LTM plays a central role in the human use of MPNs, it is instrumental to consider some of the properties of how information is represented and organized in LTM. Two properties seem particularly noteworthy.

First, human LTM is *associative* [30]. Certain concepts/pieces of information are associated with each other such as, for example, the concept of "fire" is associated with the concept of "heat". In particular, these associations are a major means of retrieving information from LTM. If a current item in WM is sufficiently strongly associated with some other piece of information in the LTM, retrieval of this other information is greatly facilitated. If, for instance, "TDI" is sufficiently strongly associated with "Turbocharged Direct Injection" in the context of cars, seeing the acronym will allow retrieving the desired information.

[7] Due to its direct connection to the fuel type Diesel it is also considered as "Turbocharged Diesel Injection".

Second, knowledge organization in human LTM is *hierarchical* [31, 32]. This means that human LTM has a tendency to be organized into categories, subcategories, and concrete instances. If asked to enumerate properties/instances in a certain domain, people will often enumerate aspects (sub)category after (sub)category. Vice versa, if people are asked to memorize a (large) list of properties, the ability to memorize the given information increases considerably, if the material can be (and is) organized hierarchically. Having expounded the crucial characteristics of human memory, we now relate them to the readability, learnability, and processing speed of MPNs.

3.4.1 Readability / Learnability

In the context of this publication, we consider an MPN readable, if a human user can map each MPN to the corresponding product (a) virtually without error and (b) without any supporting material (e.g., tables, software). Thus, the following requirements have to be met:

- The MPN has to be short enough to be held in WM completely or it has to consist of several meaningfully separable parts, each of which is short enough to be held completely in WM.
- The MPN or its meaningful parts have to be sufficiently strongly associated in LTM with the product aspects they represent.

The first requirement seems comparatively easy to achieve. A ten-arity code using letters and ciphers is able to represent about 35^{10} different product variants. The second requirement is tightly related to the learnability of the MPN, that is, to the feasibility of acquiring all necessary associations and the speed with which they can be acquired. As a result, the second requirement is much harder to satisfy as soon as we are dealing with large-scale variant spaces. There seems to be an upper limit of only around 5000 arbitrary associations that human LTM can store, while learning a good 3000 arbitrary associations took a whole year (incremental training with three sessions each day) [33]. If the human user is supposed to go beyond such limitations, the code either needs to build on and reuse existing associations or the code has to be organized hierarchically or both. The simplest form of reuse is to employ non-arbitrary mappings. For example, in the case of "TDI" the acronym is much easier to memorize than arbitrary acronyms (e.g., "XYZ"), because the letters in the acronym are the starting letters of the crucial words in the product description and, thus, the letters are already associated with the target words. More elaborate forms of reuse may involve exploiting more domain-specific knowledge of the human users. A hierarchical organization of the code would allow reducing the number of associations that need to be stored at each level of the hierarchy, while still allowing to cover a large variant space with the MPN. For example, the first digit of the MPN may signify whether the product is a car or a motorbike with the remainder of the key then being specific to the type of vehicle (car or motorbike). The upper limit of possible associations that can be stored when drawing on existing knowledge and hierarchical organization is hard to predict and will probably also depend on the individual user. Nevertheless, it is clear that the readability/learnability of the MPN increases:

- The more easily (parts of) the MPN can be maintained in working memory,
- The fewer associations have to be memorized,
- The more previous knowledge can be drawn on, and
- The clearer it can be structured hierarchically.

3.4.2 Processing speed

Processing speed can be assumed to be directly related to the length and the complexity of the MPN: The shorter the MPN and the less complex (i.e., the fewer associations) the faster the human user will be able to map the MPN to the product. Direct mappings can be assumed to be faster than hierarchical mappings, because each level in the hierarchy requires a separate mapping, while a direct mapping – once sufficiently learned – involves only a single mapping process. If a hierarchical MPN is employed, the order in which MPN parts signifying different (sub)categories appear in the MPN will have an influence in processing speed. At least in western culture languages, representing highest to lowest (sub)categories by MPN parts ordered from left to right (the predominant reading direction) will likely lead to faster MPN processing than other orderings. Consequently, the processing speed of MPN increases

- The shorter the MPN,
- The fewer associations are involved,
- The fewer hierarchical levels are involved, and
- The more the ordering of the hierarchy levels in the MPN corresponds to the reading direction.

4 USE CASES

Motivated by the diversity of the customer requirements and specificity of product configuration in the B2B markets, we propose five different application scenarios also referred to as "use cases" in the context of business modeling [34]. The use cases are based on the expert interviews and insights from the previous projects (Figure 3). To ensure comparability, we describe each of the use cases using following characteristics: (i) role of the involved actor, (ii) his/her aim and objective, (iii) current know-how level in the field, as well as (iv) what is expected from the desired solution. Consequently, with the help of the previously introduced evaluation criteria, we derive individual MPN requirements for each of the use cases (Table 1). For simplicity reasons, the costs relating to the implementation and maintenance of a specific type of MPN (e.g., establishing the new MPN structure, employee training, structure maintenance) is beyond the scope of this paper but should be considered in future research.

Starting with the customer side, one particular type of users is a *Rare Guest*, who is characterized by a low frequency of MPN use and the need for a specific (one-time) solution. These customers have little to none expert knowledge on the topic, either because of the involvement in various supply chains or due to the overall unwillingness to deal in detail with the product structure of the particular manufacturer. Their expectation towards the communication of product variety is a mere satisfaction of their request with as little effort as possible. In this way, the rare guest would not appreciate the efficiency of the MPN (e.g., through the digitalization), but would be disappointed if standard functionalities are not functioning properly. At the other end of the spectrum, there is a *Power User*. Unlike the rare guest, the power user deals with the respective MPN on a regular basis. Due to the high level of know-how both regarding the operating industry and the MPN structure, the power user is interested in a fast interaction and comparability of different variants within this particular manufacturer, in order to attain the optimal solution for a specific situation. Typically, power users are established via long-term cooperation between companies and would be interested in a high learnability of the MPN. Moreover, they personally would even get averse to switch to a purely machine-readable MPN, since this would make their own know-how obsolete.

The last external stakeholder of the MPN we consider is the *Purchasing* department, who already has a particular product configuration in mind. Similar to the rare guest, the purchasing department has little interest in the product itself (or its configuration), but mostly focuses on getting the best price and most suitable delivery time. In addition, due to the overall desire for comparability across different manufacturers, the purchasing department seeks understandability and simplicity of the MPN and, if possible, the establishment of an industry-wide standard.

Apart from the customer-driven requirements towards the MPN, manufacturer's internal departments have their own, often contradictory expectations. For example, the *Sales* department uses MPN for selling, searching, and configuring product variants in a simple and quick manner. Similar to the purchasing department of the customer, the internal sales department seeks a practical and catchy MPN structure, which can be used for the external representation of a large quantity of (homogeneous) products. With the level of know-how varying according to the position and the seniority of the sales employees, the efficiency of the sales department is dependent either on the learnability of the human-readable MPN or on the increase of the processing speed due to its digitalization.

Finally, the employees working in the internal *Production* department of the company are looking for an MPN, which would both contain information on the internal structure of the product and have a high level of learnability. Their daily usage of the MPN involves the identification of the required parts and their assembling sequence. With a highly specific background knowledge and fast production processes, production employees would appreciate a digital MPN only if it can assure a low error rate and not obstruct or slow them down in their daily activities.

5 CONCLUSION AND OUTLOOK

With the increasing customer demands for individualization and an overall growing complexity of B2B products, part manufacturers are facing new problems of communicating their product variety in a transparent and efficient way. In this context, MPNs are used as codifications of those characteristics that uniquely identify a product variant out of a modular system, thus acting both as an identifier and a description. While academia has not yet devoted enough attention to the topic of MPN, we believe that a correct deployment of the MPN is a key step to efficient variant management. Therefore, in this publication, we analyzed the main systemic and cognitive aspects of the MPN and derived evaluation criteria (i.e. readability, learnability, and processing speed) for its mapping on the underlying product structure. We then mapped these evaluation criteria on various use cases of the internal and external stakeholders, thus showing that there exists no ideal MPN, but instead it should be created depending on the respective application scenario.

This publication also highlights important topics for future research endeavors. First, despite a detailed analysis of the existing literature on manufacturing complexity combined with personal project experience of the authors, we believe that there exist additional aspects of the MPN and the product structure. Similarly,

Table 1. Various use cases regarding the deployment of MPNs

		External			*Internal*	
	Role	**Rare Guest**	**Power User**	**Purchasing**	**Sales**	**Production / Logistics**
Use case description	**Goal**	Identification, searching, configuration	Identification, searching, configuration	Acquisition, reorder	Sale, searching, configuration	Overview of the internal structure
	Use Case	Solution of an application problem	Finding an optimal variant for a specific situation	Best price and delivery time	Suitable product, possible large quantity	Fast identification of the required parts and their assembling. Low error rate
	Know-How	Low background knowledge	High background knowledge	Little interest in the product	Diverse (internal vs. external sales, seniority)	High background knowledge (highly specific)
	Desired Solution	Description of the problem, not technical detail	Fast interaction, comparability of the variants	Comparability across different manufacturers	Same description of the homogenous products	Fast transfer (e.g., location of a product part)
MPN requirements	**Read-ability**	No preferences, as long as it functions right	Human-understan-dable (without any auxiliary means)	Type of readability that enables supplier comparability	Catchy type and structure that can be used for marketing	Human-understandable (without any auxiliary means)
	Learn-ability	Not needed, since no intentions for reuse	High expectations towards the logic of the MPN structure	Not needed, since no intentions for reuse	High expectations towards the logic of the MPN structure	High expectations towards the logic of the MPN structure
	Process-ing speed	No preferences, as long as it functions right	Crucial to the efficiency of their everyday work	Preference direction machine-readable MPN	Preference direction machine-readable MPN	Crucial to the efficiency of their everyday work

future work should differentiate between industries or company-specific characteristics.

Altogether, our publication has no claims to completeness but is intended to serve as a starting point of an academic discussion on the MPN and the communication of the product variety in general. Future research should focus more on the differentiation between different layers of the company, in particular, the production and the sales layer, which may even lead to different MPNs. Another research direction is the operationalization of the above-mentioned mapping by introducing a maturity model [35] or some other decision-support framework. This may also include the task on how to find optimal MPN for a specific set of criteria. A good opportunity for creating such a model would be by following an action research, where the transformation of the company's MPN structure (e.g., towards a digital one) is supervised and documented. Finally, the monetary aspects and the area of cost efficiency in general (e.g., calculation of the possible cost savings, if a certain MPN is introduced), which were not considered in this publication, would make a major contribution, especially for the practitioners.

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